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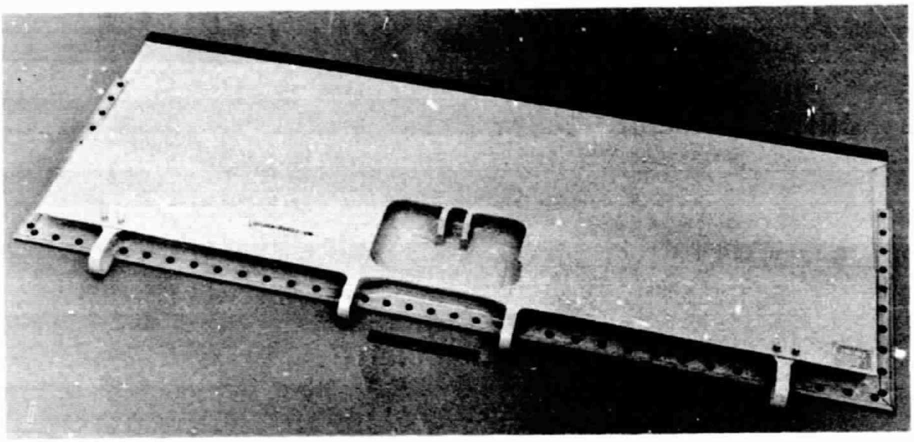
737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION

By Robert L. Stoecklin



FIRST ANNUAL REPORT
JULY 1973 THROUGH MARCH 1975

Prepared under contract NAS1-11668 by
BOEING COMMERCIAL AIRPLANE COMPANY
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Seattle, Washington 98124

for
Langley Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

This flight service report was prepared in compliance with the requirements of contract NAS1-11668 and covers the flight service experience of 108 graphite-epoxy spoilers on 737 transport aircraft and related ground-based environmental exposure of graphite-epoxy material specimens for the period from July 1973 through March 1975. Four spoilers have been installed on each of 27 aircraft representing six major airlines operating throughout the world. A flight service evaluation program of at least 5 years duration is underway. As of February 28, 1975, a total of 294 280 spoiler flight-hours and 460 686 spoiler landings had been accumulated by this fleet. Based on visual, ultrasonic, and destructive testing, there has been no evidence of moisture migration into the honeycomb core and no core corrosion. Tests of removed spoilers and of ground-based exposure specimens after the first year of service indicate no significant changes in composite strength.

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FOREWORD

This is the first progress report on the service evaluation of graphite-epoxy flight spoilers for 737 aircraft. This effort has been conducted as a portion of NASA contract NAS1-11668, "A Study of the Effects of Long-Term Ground and Flight Environment Exposure on the Behavior of Graphite-Epoxy Spoilers." The program is structured to gather and evaluate actual commercial service experience on a large number of graphite-epoxy specimens in a wide range of operating environments. Additional annual reports will be prepared and submitted for the duration of the flight service period, which is intended to provide at least 5 years of flight service.

This program is administered by the Langley Research Center of the National Aeronautics and Space Administration. Mr. Richard Pride of the Materials Division is the technical monitor.

The program is being conducted at the Boeing Commercial Airplane Company by Robert L. Stoecklin, technical leader, under the direction of Dr. R. R. June, program manager.

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Robert L. Stoecklin
Boeing Commercial Airplane Company

PROGRAM SUMMARY AND STATUS

This first annual flight service report is submitted in accordance with the requirements of contract NAS1-11668 and covers the service-evaluation portion of this NASA contract for the period of July 18, 1973 through March 31, 1975. A portion of the data contained herein has previously been reported in the quarterly progress reports.

A primary objective of this program is to produce 114 graphite-epoxy 737 flight spoilers for laboratory testing and service-evaluation deployment. One spoiler of each of the three different graphite-epoxy material systems used has been laboratory tested for stiffness and strength in partial fulfillment of FAA certification requirements. Four spoilers have been installed on each of 27 aircraft representing six major airlines operating in different environmental circumstances. These units will be monitored under actual load and environmental conditions for a period of at least 5 years. Selected units will be removed periodically to evaluate any material degradation as a function of time. Six environmental exposure racks have been fabricated and positioned at major airport terminals of the participating airlines in various parts of the world to gather ground-based environmental data to support the flight data gathered from the spoilers. Significant events that have occurred during this period include:

- Deployment of all 108 graphite-epoxy spoilers
- Deployment of six environmental exposure racks with materials specimens
- Completion of the first annual inspection of the spoilers
- Selection and removal of certain spoilers from flight service for detailed inspection and static test to failure
- Retrieval and test of the first increment of ground-based exposure specimens

As of February 28, 1975, a total of 294 280 spoiler flight-hours and 460 686 spoiler landings had been accumulated by the fleet. The high time spoiler has accumulated 3525 flight-hours on New Zealand National Airways 737 ZK-NAE. Ten aircraft have accumulated in excess of 3000 flight-hours since the beginning of the flight-evaluation program.

Based on the postservice inspections, there has been no evidence of moisture migration into the honeycomb core and no core corrosion. Failure loads for spoilers in laboratory testing after 1 year of flight service were 10% to 15% less than initial tests but still exceed 200% of design limit load. Tests of ground-based exposure specimens indicated generally less than 10% variation in material strength after 1 year of exposure when compared to results of similar baseline zero-time specimens.

Twelve spoilers were found to have sustained inservice damage. They were removed from service and have been returned to Boeing for repair. Man-hours required for repair of the first five damaged spoilers have averaged 21.2 per spoiler. After completion of repairs, the spoilers are being returned to airline service. An actuator interference problem has been identified as the principal source of inservice damage and corrective action has been taken. All participating airlines are enthusiastic about continued service evaluation.

FLIGHT SERVICE EXPERIENCE

Previous quarterly reports (ref. 1) have fully covered the fabrication, testing, certification, and deployment of the 114 spoiler units associated with task I, NASA contract NAS1-11668, with the exception of the last shipment of spoilers. The 27th and final shipset of flight spoilers was deployed by Piedmont Airlines on August 15, 1974. As a consequence, this report will deal principally with the service-evaluation effort only.

GEOGRAPHIC INSTALLATIONS

The service-evaluation program was established to place the 737 graphite-epoxy flight spoilers into a commercial service environment containing as many climatic variables as possible. No restrictions were placed on the geographical locations of candidate airlines by NASA. A survey of 737 operators disclosed that several operators were experiencing various degrees of corrosion on secondary structural honeycomb components. Since these operators functioned in a variety of climates and operated significant quantities of 737 aircraft, they were included in the list of prospective candidates. The 27 shipsets of spoilers in the program (four spoilers per shipset) were initially allocated to the following airlines in the indicated quantities.

- New Zealand National Airways—four shipsets (16 spoilers)
- Pacific Southwest Airlines—five shipsets (20 spoilers)
- Aloha Airlines—four shipsets (16 spoilers)
- Deutsche Lufthansa Airlines—six shipsets (24 spoilers)
- Piedmont Airlines—eight shipsets (32 spoilers)

This distribution was modified when PSA sold four of its participating aircraft to VASP Airlines of Sao Paulo, Brazil, in May 1974. Rather than terminate that significant portion of the program, VASP was invited to continue the spoiler evaluation on those four aircraft, which they agreed to do. VASP participation in the program is considered to be a worthwhile addition to the evaluation program. Figure 1 illustrates the geographic scope of the service-evaluation program.

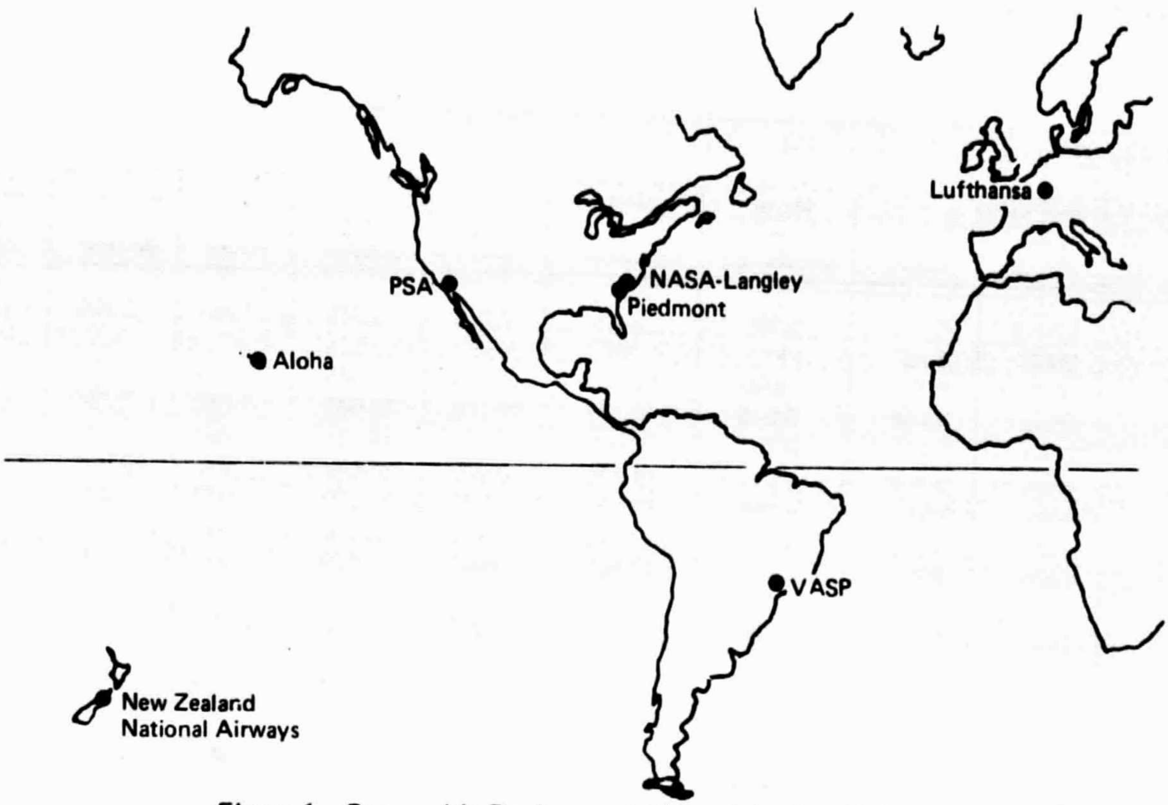

Figure 1.—Geographic Deployment of Participating Airlines

FLIGHT EXPERIENCE

The essential element in the flight service evaluation program is the commercial service exposure of the graphite-epoxy flight spoilers by scheduled carriers. The first spoiler installation was made by PSA on July 18, 1973, on 737 aircraft N987PS. The final installation was made by Piedmont Airlines on August 15, 1974, on aircraft N737N. In order to maintain a detailed accounting of the service experiences, each spoiler is maintained on a separate service record. This also permits an accounting of spoiler removals (for any reason) and reinstallation on any other aircraft and in any other mounting position on the aircraft. The total flight experience to February 28, 1975, is detailed in table 1, with the breakdown by spoiler serial number. Reinstallations are treated as a separate line item in this summary. Note that each of the graphite-epoxy material systems is designated by a separate block of serial numbers:

- Union Carbide T300/2544: 0001 to 0038
- Narmco T300/55209: 0041 to 0078
- Hercules AS/3501: 0081 to 0118

Table 2 summarizes the same data by airline. (VASP data include only flight experience since acquisition from PSA.)

Table 1.—Spoiler Service-Evaluation Program (As of February 28, 1975)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0001R	PI	5 681	3 056	7 332	5 476	1 651	2 420
0002	Test	–	–	––	–	–	–
0003	PSA	8 095	12 842	9 018	14 379	923	1 537
0003	VASP	9 018	14 379	10 970	16 695	1 952	2 316
0004	PSA	8 161	12 965	9 018	14 379	857	1 414
0004	VASP	9 018	14 379	10 970	16 695	1 952	2 316
0005	PSA	8 095	12 842	9 018	14 379	923	1 537
0005	VASP	9 018	14 379	10 970	16 695	1 952	2 316
0006	PSA	8 161	12 965	9 018	14 379	857	1 414
0006	VASP	9 018	14 379	10 970	16 695	1 952	2 316
0007	NZ	10 861	15 053	14 057	19 270	3 196	4 217
0008	NZ	10 861	15 053	14 057	19 270	3 196	4 217
0009	NZ	10 861	15 053	14 057	19 270	3 196	4 217
0010	NZ	10 861	15 053	14 057	19 270	3 196	4 217
0011	LH	11 274	15 681	14 673	19 935	3 399	4 254
0012	LH	11 274	15 681	14 673	19 935	3 399	4 254
0013	LH	11 274	15 681	14 673	19 935	3 399	4 254
0014	LH	11 274	15 681	13 329	18 216	2 055	2 535
0015	PSA	8 651	13 711	9 399	14 936	748	1 225
0015	VASP	9 399	14 936	11 257	17 090	1 858	2 154
0016	PSA	8 651	13 711	9 399	14 936	748	1 225
0016	VASP	9 399	14 936	11 257	17 090	1 858	2 154
0017	PSA	8 651	13 711	9 399	14 936	748	1 225
0017	VASP	9 399	14 936	11 257	17 090	1 858	2 154
0018	PSA	8 651	13 711	9 399	14 936	748	1 225
0018	VASP	9 399	14 936	11 257	17 090	1 858	2 154
0019	LH	11 200	14 884	14 481	18 981	3 281	4 097
0020	LH	11 200	14 884	14 481	18 981	3 281	4 097
0021	LH	11 200	14 884	14 481	18 981	3 281	4 097
0022	LH	11 200	14 884	14 481	18 981	3 281	4 097
0023	Aloha	9 207	24 932	12 087	32 738	2 880	7 806
0024	Aloha	9 207	24 932	10 974	29 694	1 767	4 762
[b]0024	Aloha	12 071	32 691	12 087	32 738	16	47
0025	Aloha	9 207	24 932	12 087	32 738	2 880	7 806
0026	Aloha	9 207	24 932	12 071	32 691	2 864	7 759
0027	PI	12 329	20 204	14 580	23 605	2 251	3 401
0028	PI	13 747	22 449	16 387	26 396	2 640	3 947
0029	PI	12 329	20 204	14 580	23 605	2 251	3 401
0030	PI	13 747	22 449	16 409	26 426	2 662	3 977
0031	PI	13 747	22 449	16 409	26 426	2 662	3 977
0032	PI	12 329	20 204	14 411	23 348	2 082	3 144
0033	PI	13 747	22 449	16 409	26 426	2 662	3 977
0034R	PI	12 329	20 204	14 580	23 605	2 251	3 401
0035	PI	5 681	3 056	7 332	5 476	1 651	2 420

See footnotes at end of table.

Table 1.–(Continued)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0036	PI	5 681	3 056	7 332	5 476	1 651	2 420
0037	PI	5 681	3 056	7 332	5 476	1 651	2 420
0038	Aloha	11 340	30 745	12 022	32 565	682	1 820
				Subtotal		97 106	146 140
0041	Test	–	–	–	–	–	–
0042	PSA	5 003	8 092	8 279	14 128	3 276	6 036
0043	PSA	4 993	8 068	8 279	14 128	3 285	6 060
0044	PSA	5 003	8 092	8 279	14 128	3 276	6 036
0045	PSA	4 993	8 068	6 896	11 280	1 902	3 212
0046	Aloha	6 447	9 087	9 110	16 040	2 662	6 953
0047	Aloha	6 447	9 087	9 110	16 040	2 662	6 953
0048	Aloha	6 447	9 087	9 103	16 022	2 655	6 935
0049	Aloha	6 447	9 087	9 110	16 040	2 662	6 953
0050	NZ	10 539	14 075	14 064	18 972	3 525	4 897
0051	NZ	10 539	14 075	14 064	18 972	3 525	4 897
0052	NZ	10 539	14 075	14 057	18 964	3 518	4 889
0053	NZ	10 539	14 075	13 138	17 747	2 599	3 672
0054	LH	11 152	15 328	14 437	19 466	3 285	4 138
0055	LH	11 152	15 328	14 437	19 466	3 285	4 138
0056	LH	11 152	15 328	14 437	19 466	3 285	4 138
0057	LH	11 152	15 328	14 437	19 466	3 285	4 138
0058	PSA	8 476	13 644	9 402	15 241	926	1 597
0058	VASP	9 402	15 241	11 068	17 343	1 666	2 102
0059	PSA	8 476	13 644	9 402	15 241	926	1 597
0059	VASP	9 402	15 241	11 068	17 343	1 666	2 102
0060	PSA	8 476	13 644	9 402	15 241	926	1 597
0060	VASP	9 402	15 241	11 068	17 343	1 666	2 102
0061	PSA	8 476	13 644	9 402	15 241	926	1 597
0061	VASP	9 402	15 241	11 068	17 343	1 666	2 102
0062	LH	11 450	15 759	14 501	19 638	3 051	3 879
0063	LH	11 450	15 759	14 501	19 638	3 051	3 879
0064	LH	11 450	15 759	14 501	19 638	3 051	3 879
0065	LH	11 450	15 759	14 501	19 638	3 051	3 879
0066	NZ	10 787	14 648	14 184	19 120	3 397	4 472
0067	NZ	10 787	14 648	14 191	19 129	3 404	4 481
0068	NZ	10 787	14 648	14 191	19 129	3 404	4 481
0069	NZ	10 787	14 648	14 191	19 129	3 404	4 481
0070	PI	13 908	22 649	16 534	26 705	2 626	4 056
0071	PI	13 908	22 649	16 534	26 705	2 626	4 056
0072	PI	13 908	22 649	16 534	26 705	2 626	4 056
0073	PI	15 070	24 630	16 537	26 785	1 467	2 155
0074	PI	13 908	22 649	16 534	26 705	2 626	4 056

See footnotes at end of table.

Table 1.– (Continued)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0075	PI	15 070	24 630	16 537	26 785	1 467	2 155
0076	PI	15 070	24 630	16 537	26 785	1 467	2 155
0077	PI	15 070	24 630	16 537	26 785	1 467	2 155
0078	Aloha	9 343	25 410	11 340	30 728	1 997	5 318
[b]0078	Aloha	9 103	16 022	9 110	16 040	7	18
				Subtotal		103 244	162 452
0081	Test	–	–	–	–	–	–
0082	LH	11 560	16 962	14 760	21 009	3 200	4 047
0083	LH	11 560	16 962	14 760	21 009	3 200	4 047
0084	LH	11 560	16 962	14 760	21 009	3 200	4 047
0085	LH	11 560	16 962	14 760	21 009	3 200	4 047
0086	NZ	5 587	8 565	8 869	12 945	3 282	4 380
0087	NZ	5 587	8 565	8 869	12 945	3 282	4 380
0088	NZ	5 587	8 565	8 869	12 945	3 282	4 380
0089	NZ	5 587	8 565	7 272	10 794	1 685	2 229
[b]0089	NZ	8 771	12 820	8 869	12 945	98	125
0090	Aloha	5 623	7 992	6 788	10 937	1 165	2 945
[b]0090	Aloha	11 344	30 728	12 022	32 565	678	1 837
0091	Aloha	5 623	7 992	8 035	14 174	2 412	6 182
0092	Aloha	5 623	7 992	8 035	14 174	2 412	6 182
0093	PI	13 879	22 839	16 272	26 469	2 393	3 630
0094	PI	13 879	22 839	16 272	26 469	2 393	3 630
0095	PI	13 879	22 839	16 272	26 469	2 393	3 630
0096	PI	13 879	22 839	16 272	26 469	2 393	3 630
0097	–	–	–	–	–	–	–
0098	Aloha	9 244	25 150	12 022	32 565	2 778	7 415
0099	PI	10 290	15 517	12 847	19 387	2 557	3 870
0100	PI	12 641	20 584	14 929	24 093	2 288	3 509
0101	PI	10 290	15 517	12 847	19 387	2 557	3 870
0102	PI	10 290	15 517	12 847	19 387	2 557	3 870
0103	PI	12 641	20 584	14 929	24 093	2 288	3 509
0104	Aloha	9 244	25 150	11 340	30 745	2 096	5 595
0105	Aloha	9 244	25 150	9 343	25 410	99	260
[b]0105	Aloha	6 916	11 247	8 035	14 174	1 119	2 927
0106	Aloha	5 623	7 992	8 035	14 174	2 412	6 182
0107	Aloha	9 244	25 150	12 022	32 565	2 778	7 415
0108	PSA	8 621	13 711	9 568	15 160	947	1 449
0108	VASP	9 568	15 160	11 322	17 314	1 754	2 154
0109	PSA	8 621	13 711	9 568	15 160	947	1 449
0109	VASP	9 568	15 160	11 322	17 314	1 754	2 154
0110	PSA	8 621	13 711	9 568	15 160	947	1 449
0110	VASP	9 568	15 160	11 322	17 314	1 754	2 154

See footnotes at end of table.

Table 1.—(Concluded)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0111	PSA	8 621	13 711	9 568	15 160	947	1 449
0111	VASP	9 568	15 160	11 322	17 314	1 754	2 154
0112	LH	11 587	16 011	14 536	19 767	2 949	3 756
0113	LH	11 587	16 011	14 536	19 767	2 949	3 756
0114	LH	11 587	16 011	14 536	19 767	2 949	3 756
0115	LH	11 587	16 011	14 536	19 767	2 949	3 756
0116	PI	10 290	15 517	12 847	19 387	2 557	3 870
0117	PI	12 641	20 584	14 929	24 093	2 288	3 509
0118	PI	12 641	20 584	14 929	24 093	2 288	3 509
				Subtotal		93 930	152 094
					Grand total	294 280	460 686

[a]PI is Piedmont Airlines.
VASP is Viacao Aerea Sao Paulo Airlines, Brazil.
NZ is New Zealand National Airways.
LH is Lufthansa German Airlines.

[b]Reinstallation

Table 2.—Flight Spoiler Service Experience (Through February 28, 1975)

Airline	Number of aircraft in evaluation	Number of spoilers in evaluation	Total spoiler hours since installation	Total spoiler landings since installation
PSA	1	4	25 783	44 330
Aloha	4	16	41 683	110 070
New Zealand	4	16	51 189	68 632
Lufthansa	6	24	75 316	94 965
Piedmont	8	32	71 389	107 785
VASP	4	16	28 920	34 904
Total	27	[a]108	294 280	460 686

[a]Current total now 105 spoilers, with 3 spoilers removed for static testing.

Figure 2 is a plot of the history of flight-hours and landings, with the experience curves projected into late 1975.

Figures 3 and 4, photos taken at the Winston-Salem, N.C., and Frankfurt/Main airports, respectively, show representative equipment involved in the program and lend substance to the geographical scope of the program.

SPOILER REMOVALS FROM SERVICE

Several spoiler units were removed from service and reinstalled at a later date. Table 3 summarizes these removals and notes the reasons and disposition in each case.

The most significant problem area has been the occurrence of upper surface skin blisters. This problem has been investigated and determined to be the result of an interference between the actuator rod end and the inner surface of the upper skin, when the rod end is in the "hard-over" position. Since the graphite skin is thicker, ≈ 0.091 vs 0.081 cm (≈0.036 vs 0.032 in.), and stiffer than its counterpart on the production aluminum spoiler, the graphite skin cannot accept the forced deflection without suffering an interlaminar shear failure. This type of problem was first noted in October 1973 on an Aloha 737. After the third such incident was reported in July 1974, a fleet survey of Aloha was conducted by the program technical leader. This survey disclosed six additional spoiler blisters not previously reported. Discovery of the rod-end interference problem led to a program-wide survey of all participating airlines to assess the extent of blister damage. This survey (October through November) disclosed three additional blistered spoilers on aircraft of two of the other airlines.

The immediate corrective action available was to replace the offending rod ends with the optional rod end which offers a spherical housing configuration (fig. 5). Replacement rod ends were furnished to Aloha, and rod ends for the remaining airlines were distributed during the January 1975 inspection tour.

During the January 1975 inspection tour, seven previously unreported blistered spoilers were identified, making a total of 19 spoilers so damaged. In order to preclude compromising the evaluation program, arrangements have been made with the airlines involved to return the blistered spoilers to Boeing for repair, after which the spoilers will be returned to the respective airlines for reinstallation. These reinstallations account for the multiple entries for certain spoilers in the flight service summary. (Refer to table 1.)

In June 1974, New Zealand National Airways reported that spoiler S/N 0089 had been inadvertently damaged by a control cable during aircraft overhaul. The nature of the damage was a slot cut through the spoiler thickness for a length of approximately 6.6 cm (2.6 in.) from the trailing edge. This damage has been repaired by Boeing, and the spoiler has been returned to National Airways and reinstalled.

Since the blister problem is totally unrelated to the service performance of the graphite-epoxy spoiler and the only other removal incident (S/N 0089) was attributable to maintenance damage, the appraisal of spoiler performance at 19 months after initial introduction into service can best be assessed as "no problems." The unyielding nature of

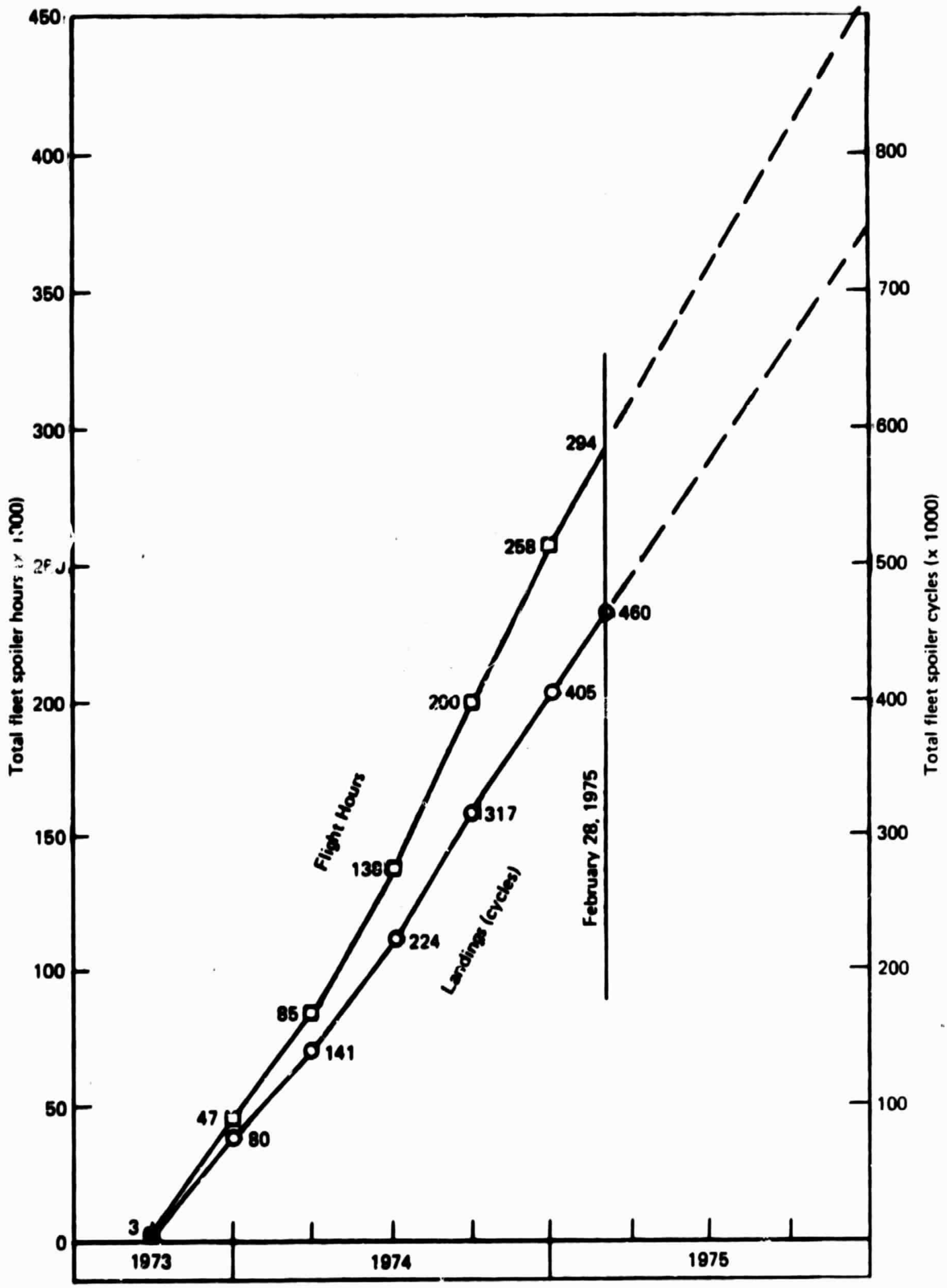

Figure 2.–Cumulative Fleet Flight-Hours and Landings

Figure 3.—Participating 737 at Winston-Salem Airport

Figure 4.—Participating 737 at Frankfurt/Main Airport

Table 3.—Flight Spoiler Removal Summary (As of February 28, 1975)

Spoiler serial number	Airline	Date removed	Reason for removal	Action taken	Final disposition
0014	Lufthansa	7-29-74	1-yr evaluation	NDT and skin repair	Static test
0024	Aloha	7-11-74	Upper skin blister	NDT and skin repair	Reinstalled
0026	Aloha	2-25-75	Upper skin blister	NDT and skin repair	To be reinstalled
0028	Piedmont	2-24-75	1-yr evaluation	NDT	To spares
0032	Piedmont	1-28-75	Upper skin blister	NDT and skin repair	To be reinstalled
0045	PSA	7-14-74	1-yr evaluation	NDT	To spares
0048	Aloha	2-25-75	Upper skin blister	NDT and skin repair	To be reinstalled
0052	New Zealand	2-27-75	Upper skin blister	NDT	To be reinstalled
0053	New Zealand	9-24-74	1-yr evaluation	NDT	Static test
0059	VASP	1-10-75	Upper skin blister	NDT and skin repair	To be reinstalled
006[illegible]	New Zealand	2-27-75	Upper skin blister	NDT	To be reinstalled
0078	Aloha	10-24-74	Upper skin blister	NDT and skin repair	Reinstalled
0089	New Zealand	6-21-74	Maintenance damage to TE	NDT, skin and core repair	Reinstalled
0090	Aloha	5-2-74	Upper skin blister	NDT and skin repair	Reinstalled
0104	Aloha	10-25-74	Upper skin blister and 1-yr evaluation	NDT	Static test
0105	Aloha	10-17-73	Upper skin blister	NDT and skin repair	Reinstalled

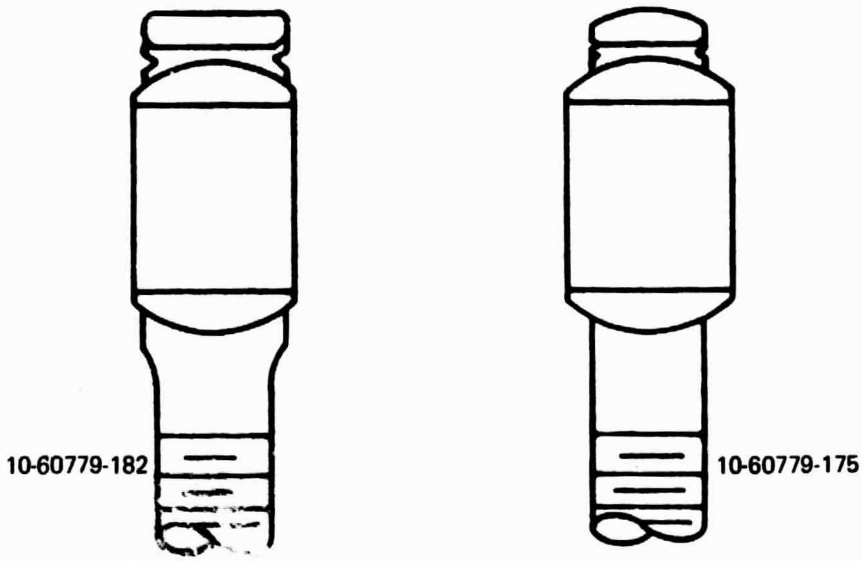

Figure 5.—Actuator Rod End Cross Sections

the laminates points out very clearly that extreme caution must be exercised to avoid undesired forced displacements of the laminates. No evidence of corrosion or deterioration of the skin laminates has been observed. One case of corrosion of the aluminum bearing doublers on the spoiler lower skin was observed (spoiler S/N 0048, fig. 6). Investigation of this condition is continuing.

Five spoilers were selected at random for removal following the first year of service. Visual inspection of these units showed no detectable defects and only the oil and dirt associated with trailing edge components, except for spoilers S/N 0014 and 0104. Spoiler S/N 0014 showed evidence of delamination of a repair on the upper surface skin above the center hinge fitting (fig. 7). Spoiler S/N 0104 showed an upper surface skin blister, approximately 3 cm (1.2 in.) in diameter, above the center hinge fitting (CHF), which was not repaired prior to its destruction in static test.

All five spoilers were reexamined by ultrasonic testing techniques in the same manner as was employed in the original fabrication process. Comparisons between the two sets of ultrasonic recordings showed no detectable internal defects or disbonds and confirmed the external defects on S/N 0014 and 0104 which were visually noted.

The spoilers that were subjected to static test following 1 year of service evaluation (S/N 0014, 0053, and 0104) were subsequently sawed open and examined for evidence of corrosion. Careful inspection of the inside surface of each skin laminate showed no evidence of corrosion.

In addition, no evidence of deterioration was found attributable to the presence of grease, oil, dirt, or Skydrol.

STATIC TEST RESULTS

As a portion of the service-evaluation program, additional static testing of spoilers removed from flight service was conducted. The plan was to test one randomly selected spoiler of each graphite-epoxy material system to destruction. After 1 year of service, comparison of test data with the test data obtained on similar spoilers having no service exposure experience would be made to ensure a continued level of safety margin.

The spoilers selected for static test are listed in table 4.

Table 4.—Static Test Spoilers

Graphite-epoxy material system	Spoiler serial number	Operator airline	Total flight-hours in service	Total time in service
T300/2544	0014	Lufthansa	2055	11 mo, 3 days
T300/5209	0053	New Zealand	2599	14 mo, 1 day
AS/3501	0104	Aloha	2096	13 mo, 0 days

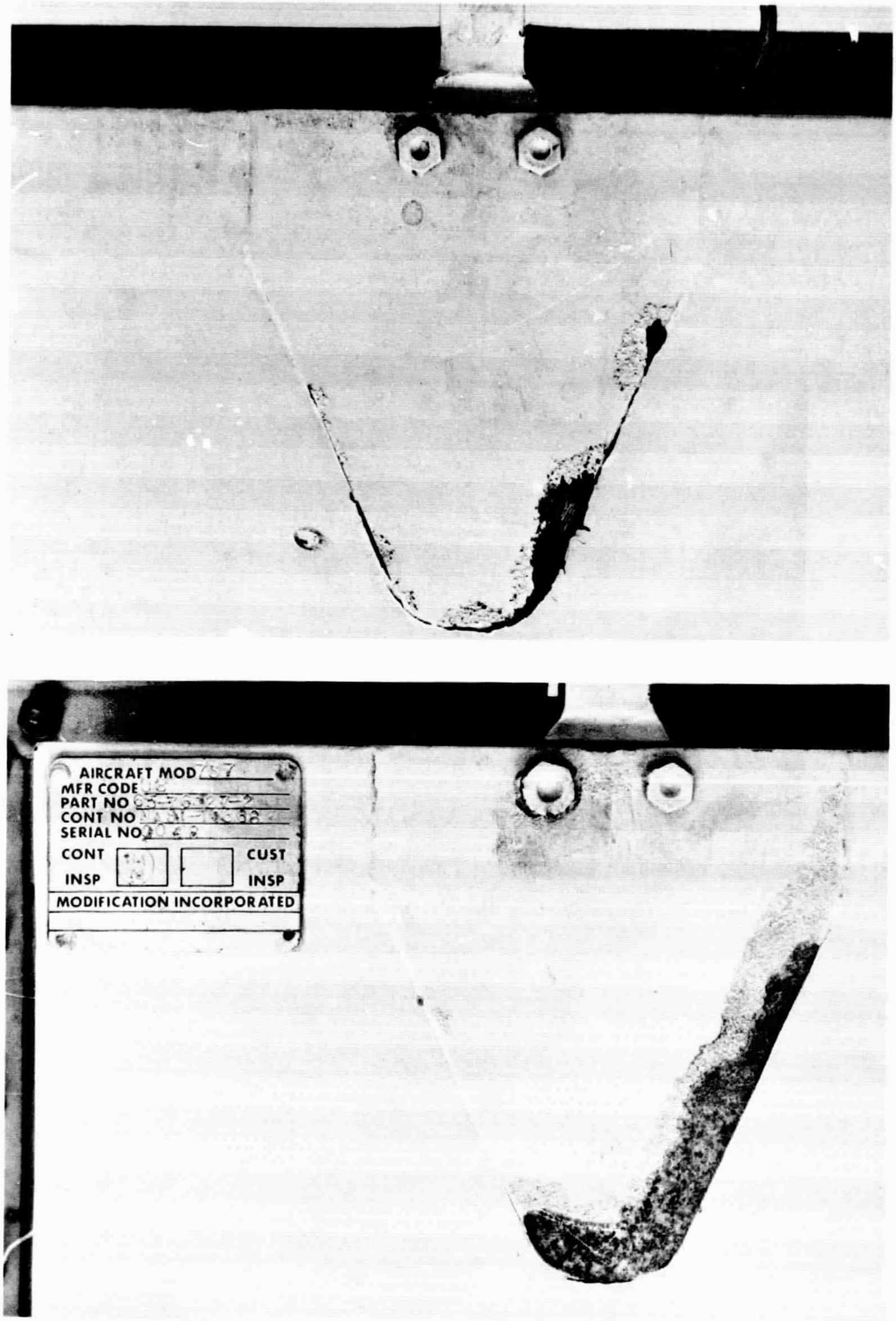

Figure 6.—Corrosion on -23 Doubler

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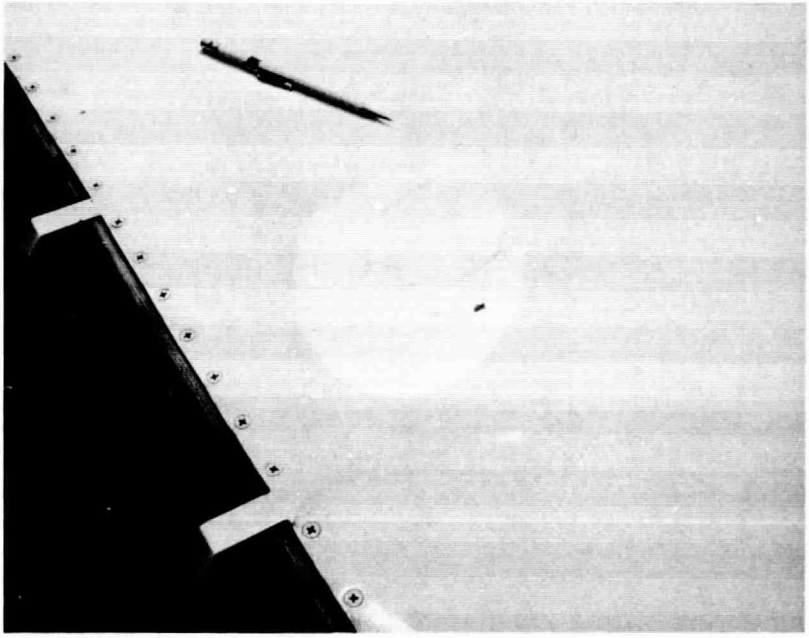

Figure 7.—Upper Surface Repair Delamination on S/N 0014

The static test setup from the original certification testing was used to conduct these tests. All three tests were conducted on the same working day. Test results are plotted in figures 8, 9, and 10, with the corresponding plots of the certification testing included in each figure. Failure load levels of the current tests are considered satisfactory since they equal or exceed the values achieved by the production aluminum spoiler (ref. 1, Third Quarterly Report, April 1973). Photos of the failed test spoilers are shown in figures 11, 12, and 13.

In comparing the test results of the current test series with the original certification testing, the following differences were noted:

1. Initial failure of S/N 0014 was brought about by the combination of shearing of the -11 aluminum doubler above the CHF and failure of the repair patch on the upper skin above the CHF. The failure load achieved was attained despite a "resin only" joint around the edges of the repair. Repair procedures have been modified to include EA 9628 adhesive in the repair lap joints. Although the failure occurred in the skin repair area, the percentage loss in failure load was essentially no greater than for the other two test specimens. Failure of the comparable certification test spoiler (S/N 0002) was attributable to lower surface skin buckling near the CHF due to deflection of the CHF.

2. Failure mode of the T300/5209 spoiler (S/N 0053) has been assessed as a primary lower skin buckling immediately adjacent to the CHF. An additional failure of the -11 aluminum doubler under the upper skin precipitated the upper skin tension failure. Both failures were influenced by deflection of the CHF. Failure of the comparable certification test spoiler (S/N 0041) was attributed to upper surface skin tension failure precipitated by yielding and failure of the CHF.

3. Failure mode of the AS/3501 spoiler (S/N 0104) was indicative of a shear failure in the bondline between the honeycomb core and the CHF, with secondary shear failure in the honeycomb core along the spoiler centerline. The comparable certification test spoiler (S/N 0081) failed in buckling of the lower skin near the CHF, with a resulting honeycomb core shear failure along the spoiler centerline.

SERVICE PROBLEMS/REPAIRS

During the course of the 19-1/2 months that the service-evaluation program has been in progress, a number of flight spoilers have been returned to Boeing. These returns were occasioned by one of the following reasons:

- Scheduled 1-year removal (4 units)
- Upper surface skin blister (11 units)
- Maintenance damage (1 unit)

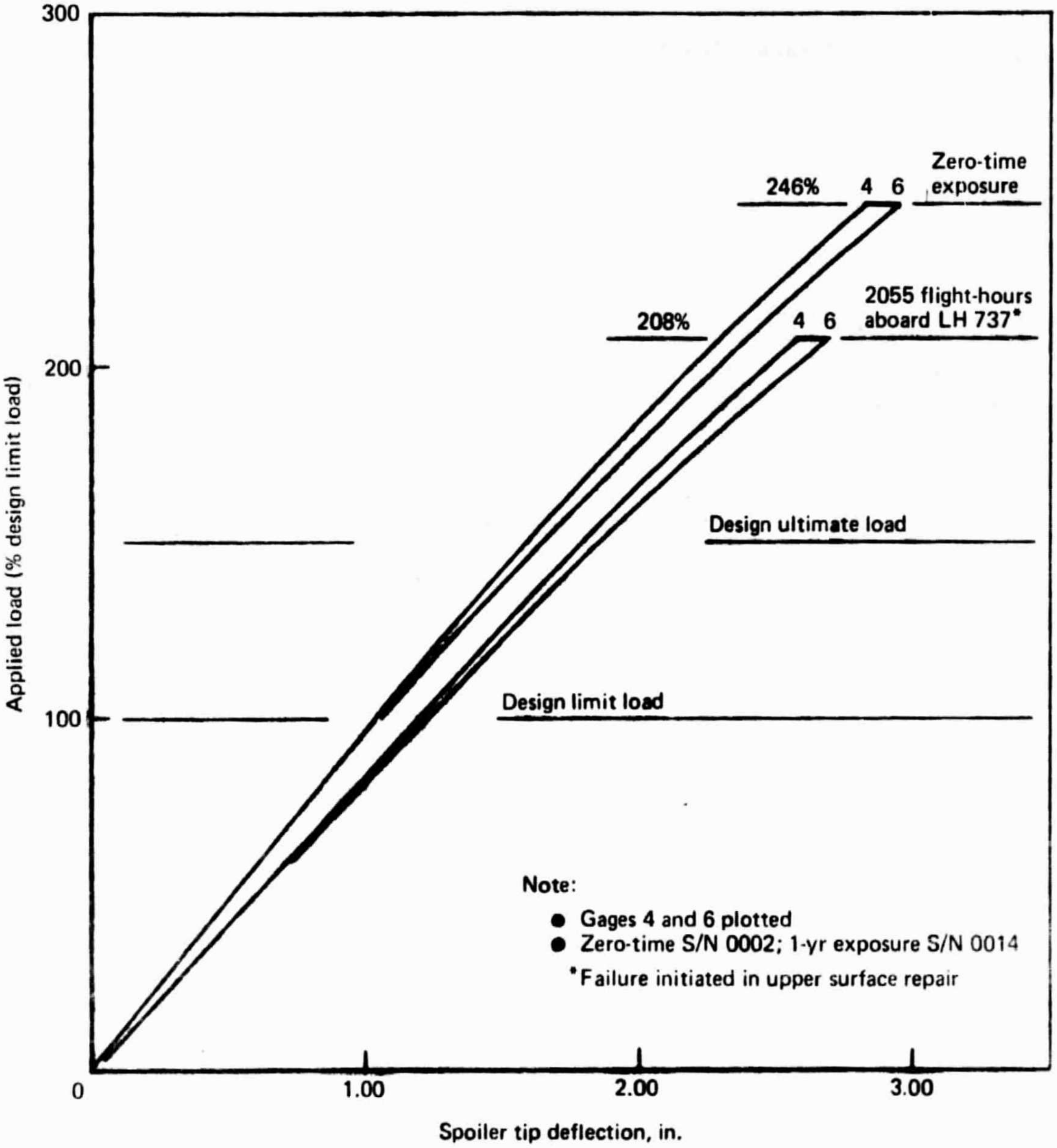

Figure 8.—Load-Deflection Curves—Zero-Time and 1-Year Exposure (Union Carbide T300/2544 Material System)

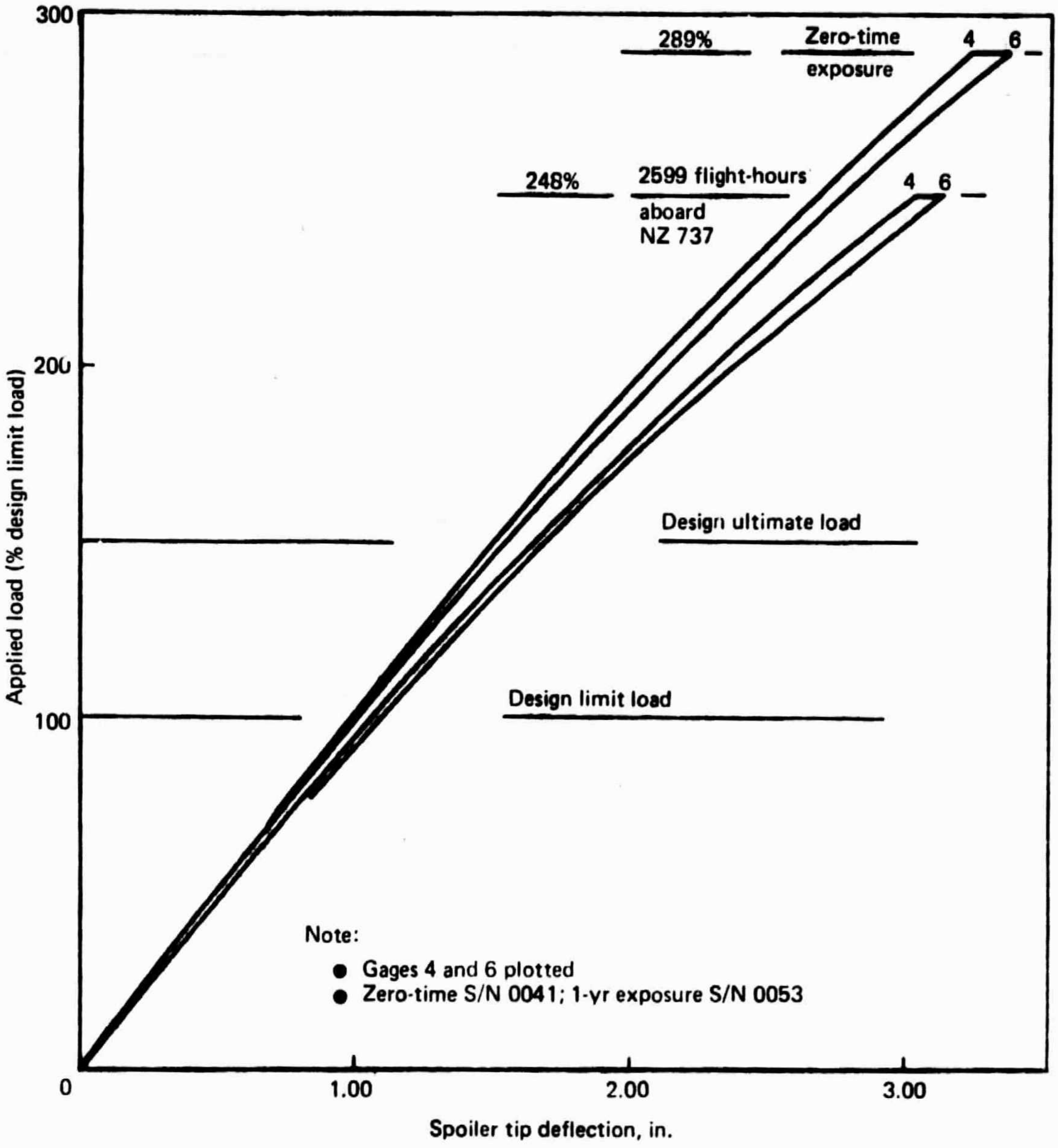

Figure 9.—Load-Deflection Curves—Zero-Time and 1-Year Exposure (Narmco T300/5209 Material System)

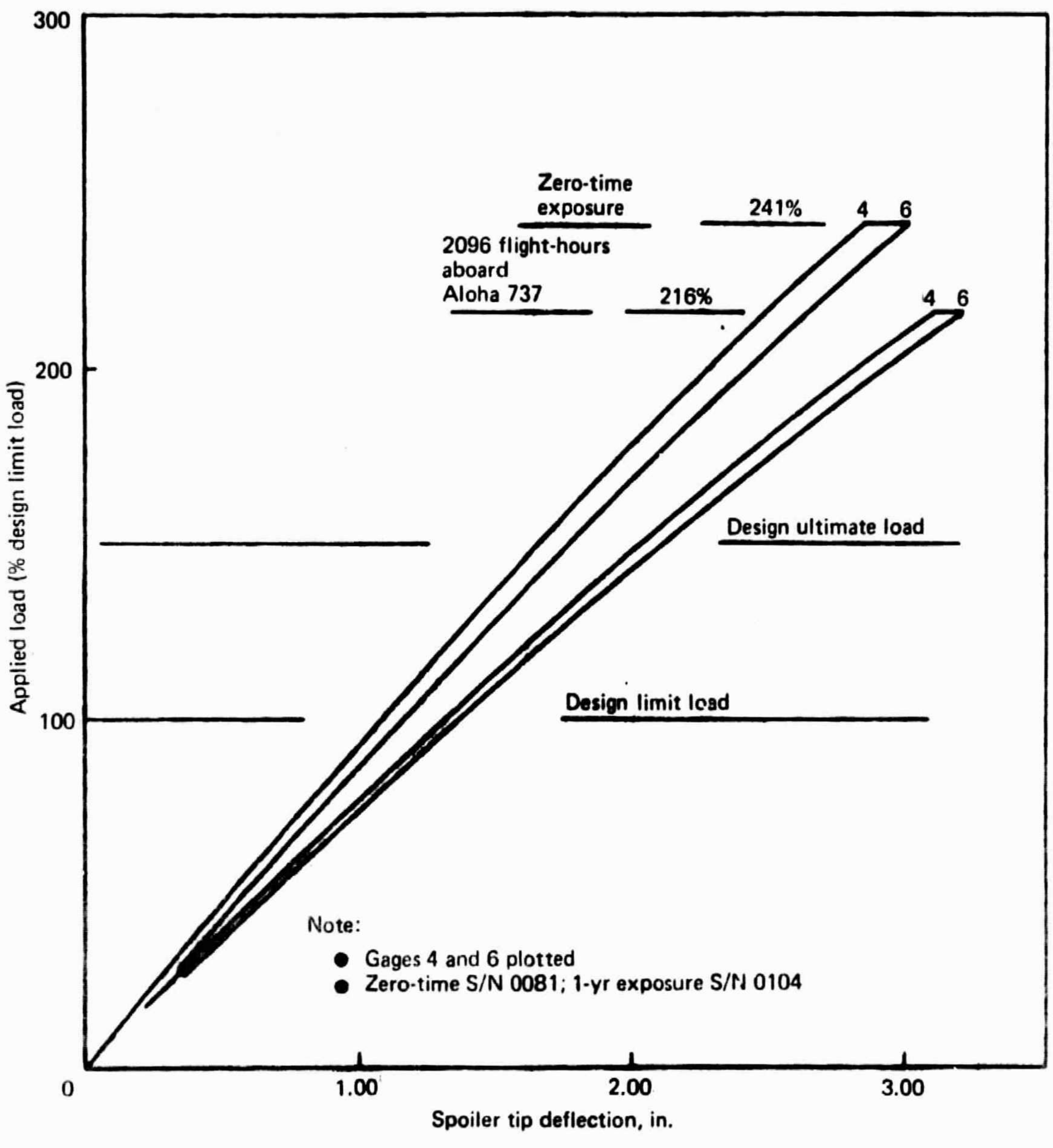

Figure 10.—Load-Deflection Curves—Zero-Time and 1-Year Exposure (Hercules AS/3501 Material System)

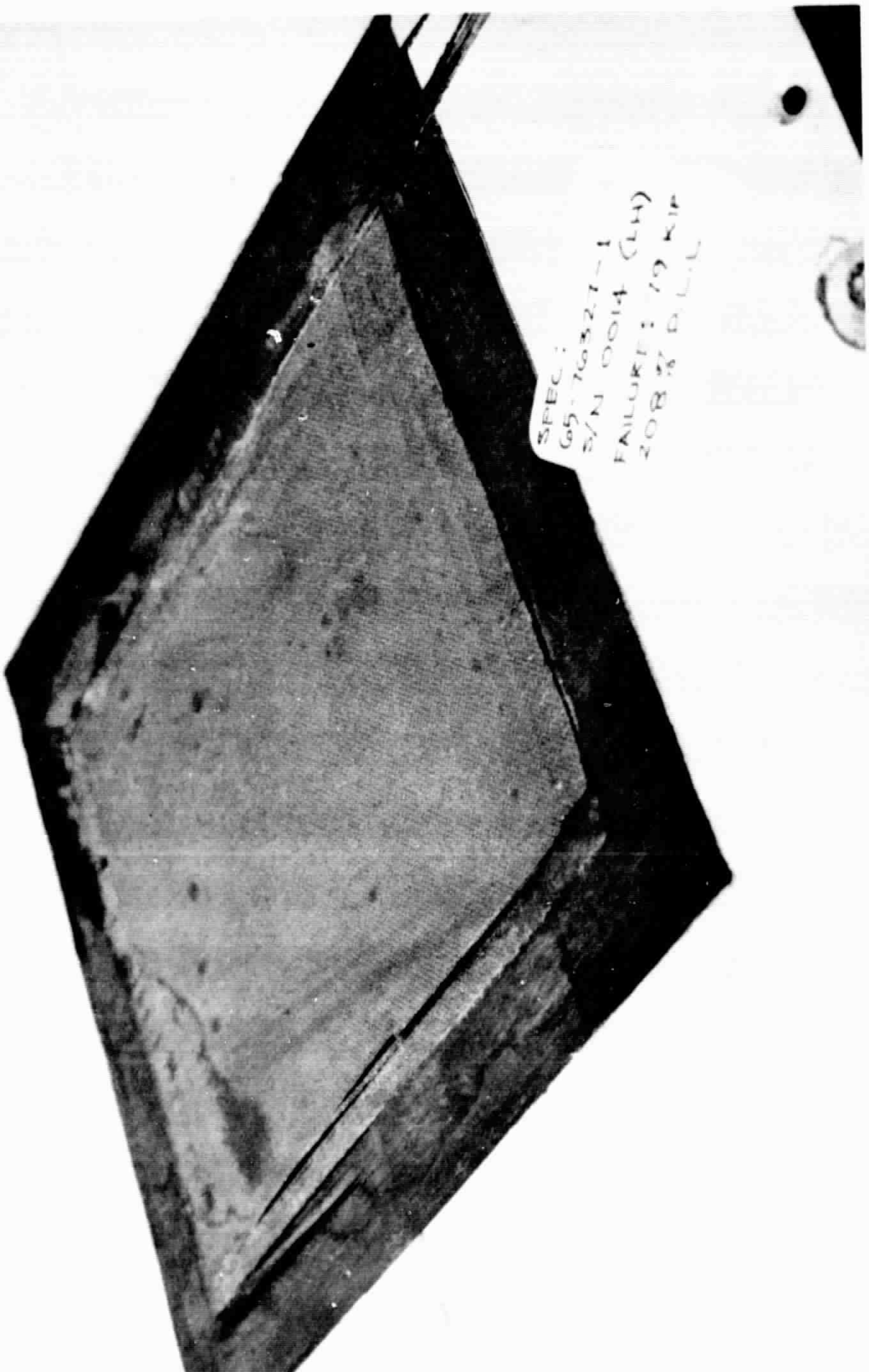

Figure 11.—Failure of S/N 0014 Through Repair

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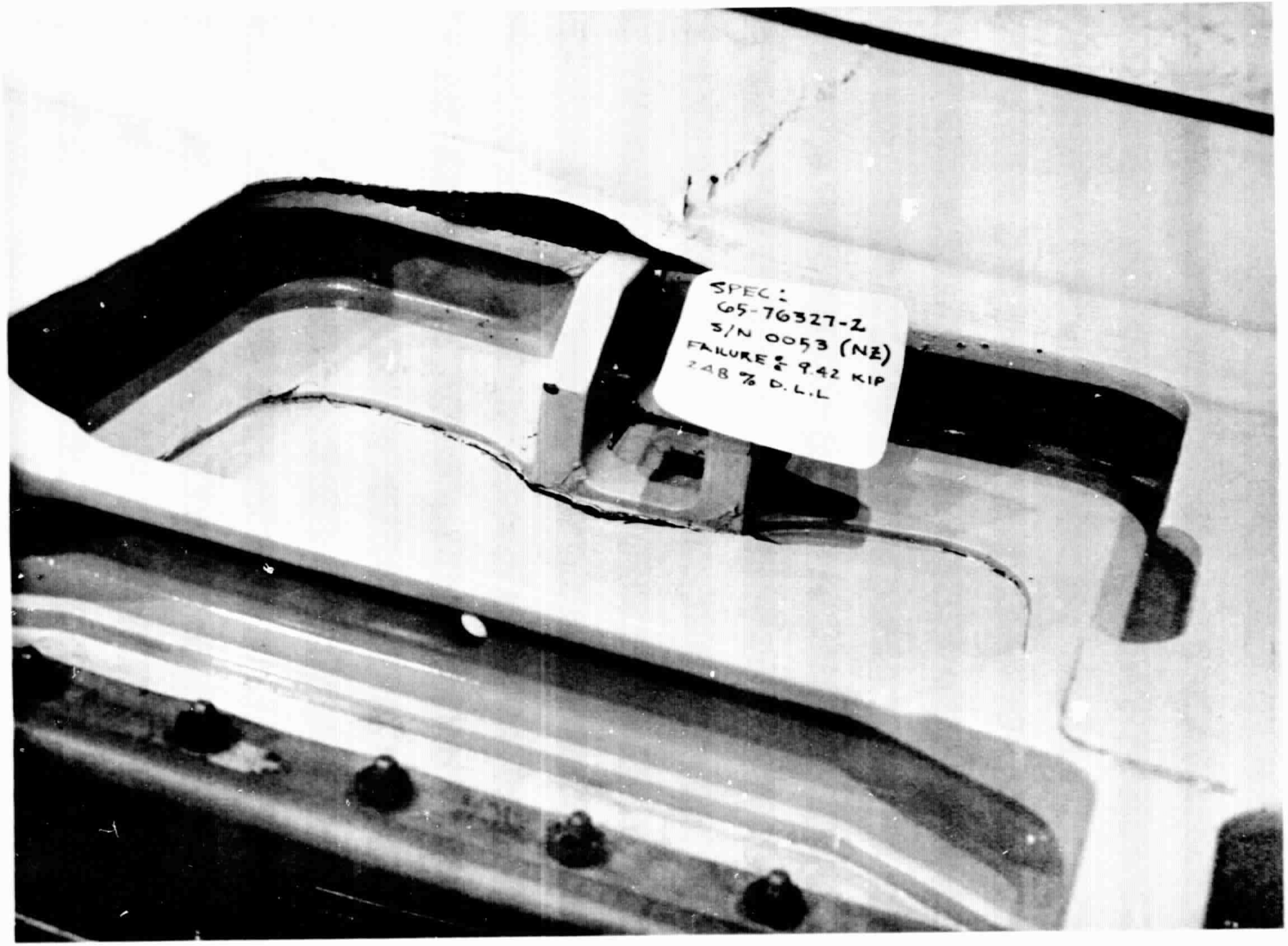

Figure 12.—Failure of S/N 0053 Above and Below Center Hinge Fitting

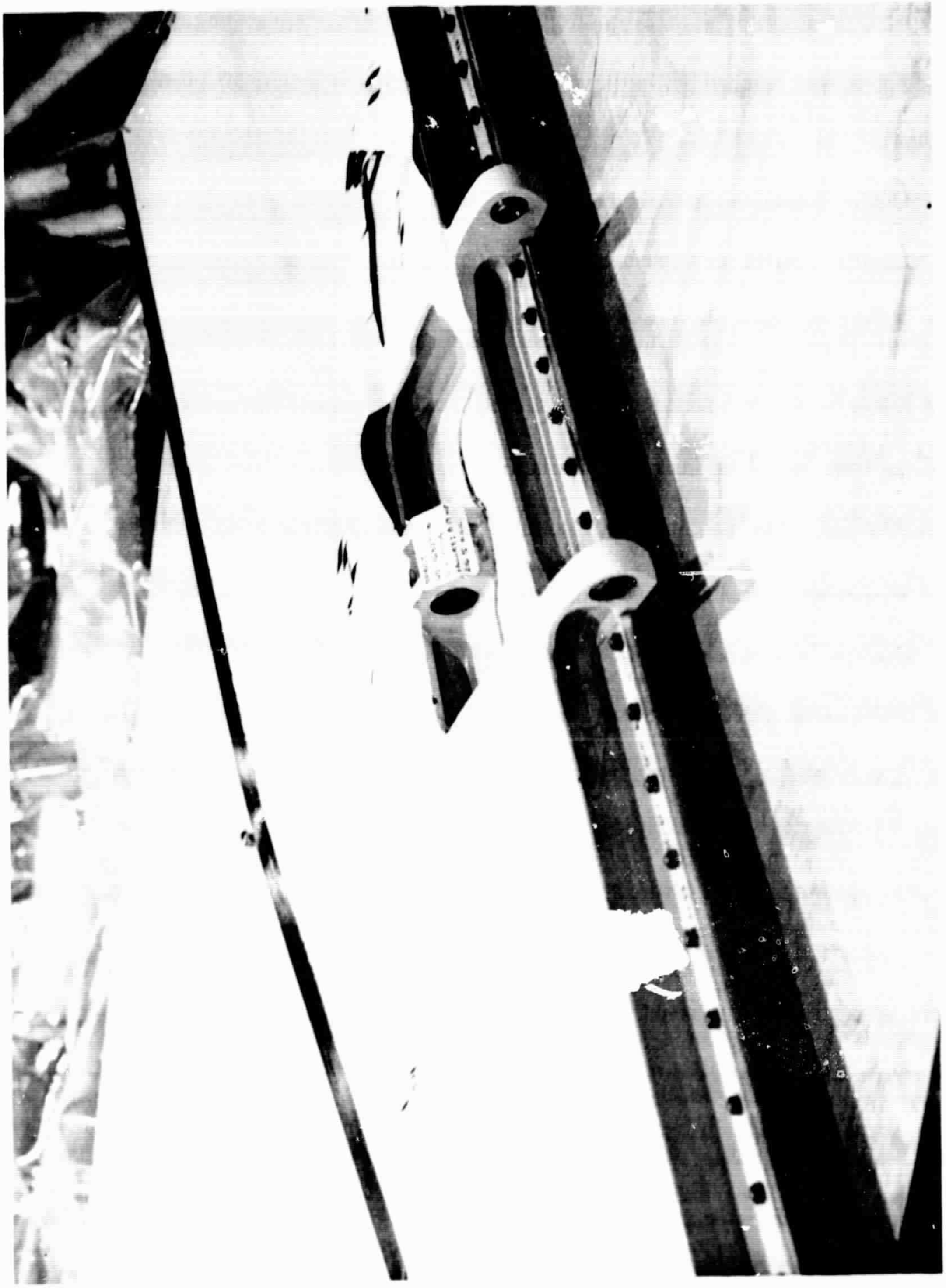

Figure 13.—Failure of S/N 0104 Adjacent to Center Hinge Fitting

A discussion of the background of the upper surface skin blister problem was made in the "Removals From Service" section of this report. This problem alone accounted for 90% of the total number of unplanned removals. It is interesting to note that 7 of the 11 blister removals to date have come from Aloha 737's. Aloha also accounted for the highest number of cycles (landings) of graphite-epoxy flight spoilers in the service evaluation.

Agreement was reached with the participating airlines to return all blistered spoilers to Boeing for repair. The procedure for repair was as follows, after receipt of a spoiler at Boeing:

- Quality Control initiated rejection tag.
- Quality Control performed complete color C-scan.
- MRB engineer wrote repair disposition.
- Shop removed defect from skin and prepared laminate for repair layup. For blister repair, each ply of skin was stepped back approximately 0.6 cm (0.25 in.) from the preceding ply, and the repair ply was overlaid to provide an adequate shear tie. Film adhesive was added in the ply overlap.
- Shop laid up prepreg repair and completely bagged spoiler in bond assembly tool.
- Spoiler was autoclave-cured and debagged.
- Quality Control performed color C-scan.
- MRB engineer accepted repair.
- Spoiler surface was refinished; seals and bearings were reinstalled; spoiler was prepared for shipment.

In one instance (S/N 0024), the spoiler, with the upper skin repaired, was not placed in the bonding assembly tool. Instead, a partial bag was prepared covering the repair only. Following autoclave cure and bag removal, a large oval-shaped void, approximately 20 x 30 cm (7.8 x 11.7 in.), was visually noted in the central portion of the lower skin.

The color scan which followed the repair confirmed the void. To visually assess the problem, an oval section of skin was removed (fig. 14). Further examination disclosed that those areas adjacent (in the spanwise direction) to the initial void were also voided or weakly attached. Progressive removal of the entire lower skin was successfully accomplished (fig. 15). An entire new lower skin was successfully bonded to the spoiler frame, with the subsequent NDT inspection showing a void-free bondline. Following the repainting and reinstallation of details, the spoiler was returned to service.

Photos of the New Zealand spoiler (S/N 0089) show the damaged trailing edge before repair (fig. 16) and after repair (fig. 17).

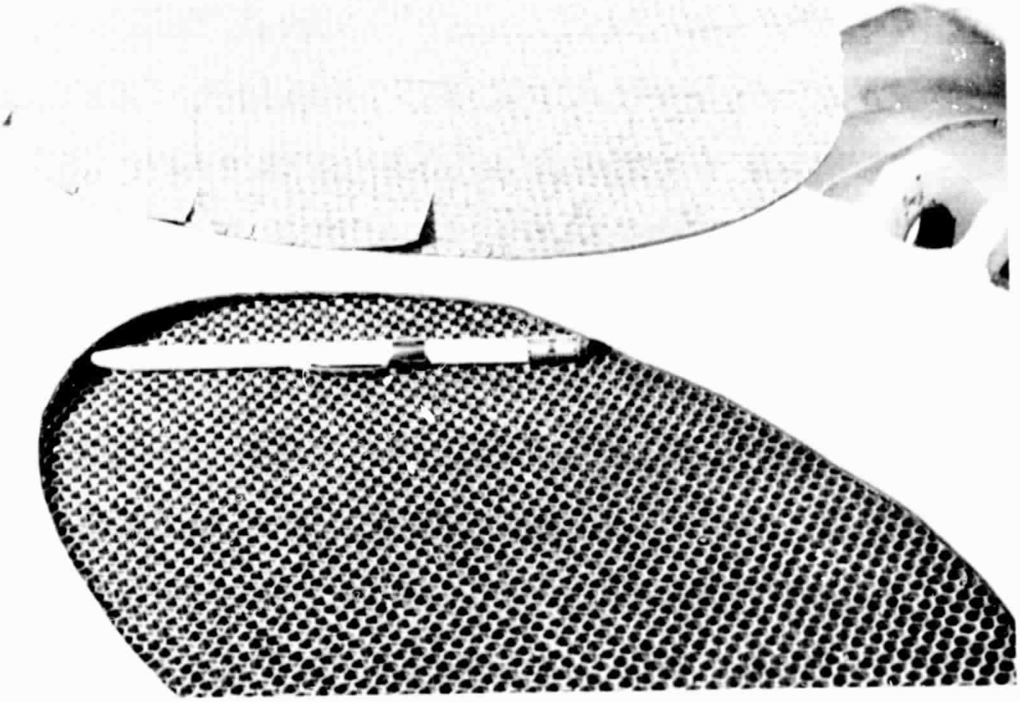

Figure 14.—Skin Removed From S/N 0024

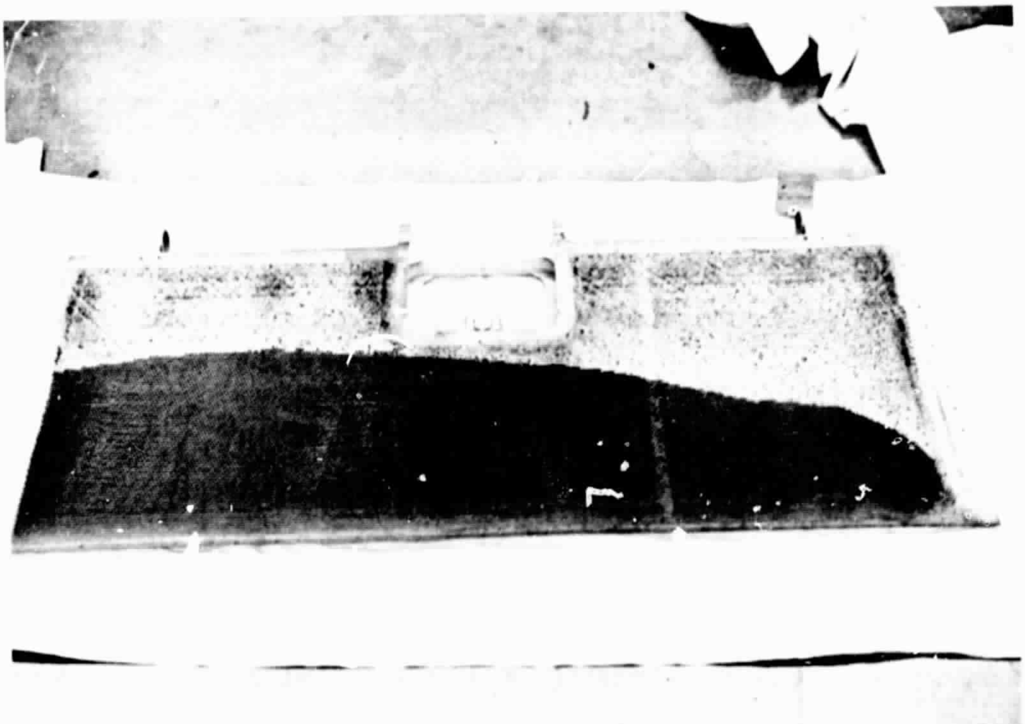

Figure 15.—Lower Skin Completely Removed From S/N 0024

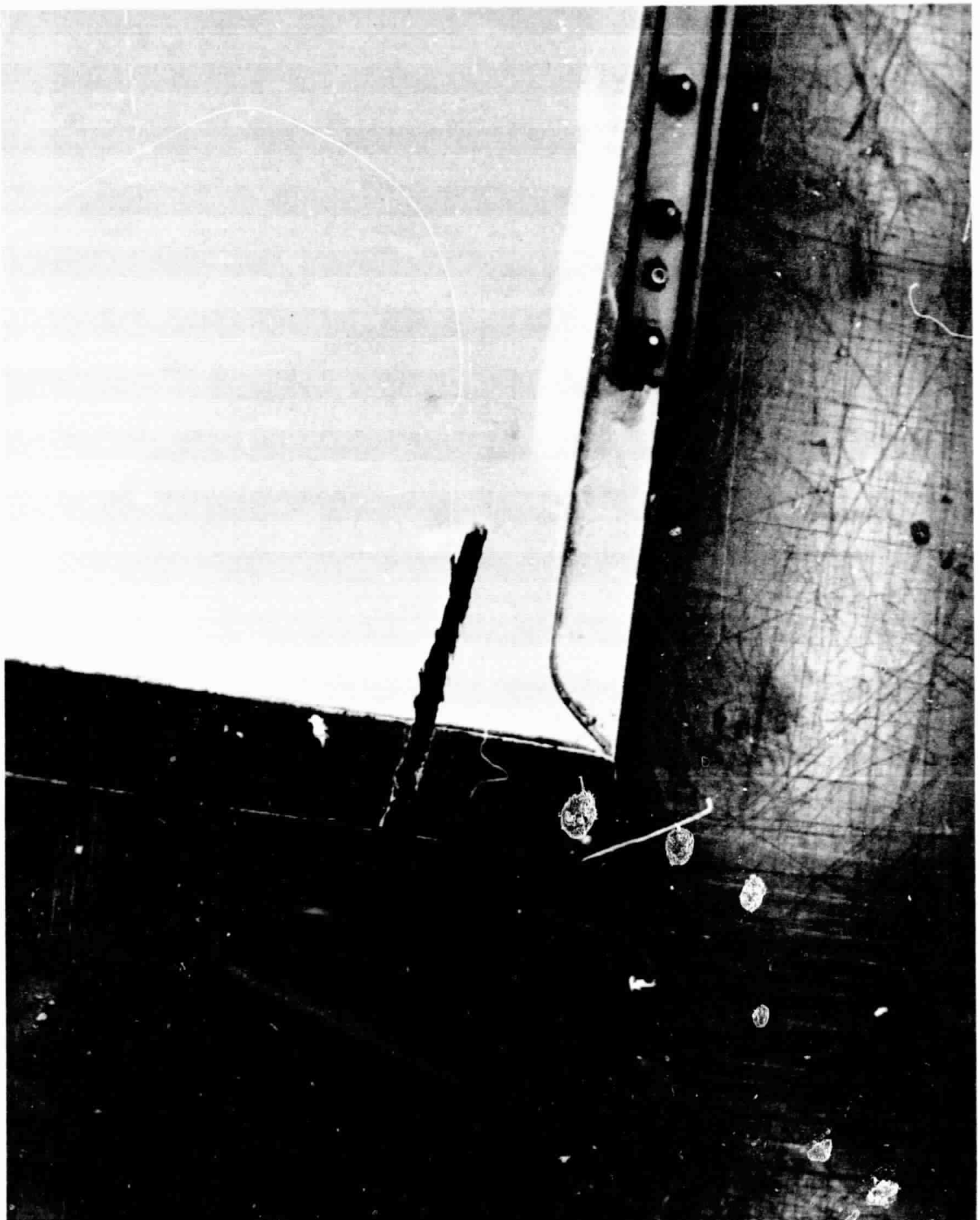

Figure 16.—Damaged Trailing Edge of S/N 0089

Figure 17.–Repaired Trailing Edge of S/N 0089

REPAIR COSTS

Several repair requirements for spoiler skin laminates were generated as a result of circumstances discussed in the "Removals From Service" section of this report. Upon recognition of the repair need, those spoiler units so identified were returned to Boeing for repair.

A direct charge system was employed in the Auburn fabrication facility to track man-hour costs associated with each repair. Each unit was identified in the accounting system using the rejection tag serial number to identify charges for each unit. Table 5 gives the breakdown of the repair hours accumulated on five completed repairs. Refinishing man-hours have been prorated when more than one unit was processed at one time. No material costs have been included in this accounting as they were considered to be insignificant. Charges for the repair of S/N 0024 reflect the additional effort of replacing the lower skin.

Table 5.—Repair Cost Data (Man-Hour Charges)

Spoiler serial number	Airline	Final assembly	Detail assembly	Production control	Painting and finishing	Total
0024	Aloha	3.3	18.5	0.3	7.7	29.8
0089	New Zealand	4.1	6.0	0.3	7.7	18.1
0090	Aloha	4.1	8.5	0.2	7.7	20.5
0014	Lufthansa	5.3	10.8	0.2	0	16.3
0078	Aloha	2.8	8.5	0.2	9.6	21.1
Total		19.6	52.3	1.2	32.7	105.8
Average		3.92	10.46	0.24	6.54	21.16

Each spoiler repair required hand preparation of the laminate to remove the defect, hand layup, and autoclave cure of the graphite-epoxy repair patch. Engineering direction for each repair was individually prepared. Each unit was nondestructively inspected both prior to and following each repair.

GROUND-BASED ENVIRONMENTAL SERVICE

Concurrent with the flight service evaluation program of the flight spoilers, specimens of the same composite material systems are being subjected to long-term environmental exposures at the main terminals of five of the participating airlines and at the NASA-Langley Research Center. Periodic removal and test of the exposed specimens are being performed to determine if the material properties are being degraded by ground-based exposure and to provide correlation with the static strength tests of spoilers removed from flight service.

An installation device was developed which allows multiple specimens to be mounted in individual panels, five of which are fastened to the exposure rack frame with quick-release fasteners that permit removal of one panel without disturbing adjacent panels. Figure 18 shows a typical installation of the exposure rack assembly on the roof of the VASP headquarters building at Congonhas Airport in Sao Paulo, Brazil. A closeup view of one panel is included. Similar installations have been made at airline terminals at Wellington, New Zealand; Frankfurt, Germany; Honolulu, U.S.A.; San Diego, U.S.A.; and at NASA-Langley Research Center. Short beam shear, flexure, and compression specimens are being exposed. At specified intervals, one panel is removed from each rack, packaged to maintain the local moisture content, and shipped to Langley Research Center for testing. Initial specimen exposure began in the fall of 1973 and will continue for at least 5 years.

Tables 6, 7, and 8 give results of tests on shear, flexure, and compression specimens of the three graphite-epoxy material systems following 1 year of environmental exposure at five of the six sites. Comparisons with the test results on unexposed baseline specimens are made in the bar graphs of figures 19, 20, and 21. These three material systems show generally less than 10% change in mechanical properties. Moisture pickup by these materials has been generally less than 1% based on changes in specimen weight. Although the change in material properties is about the same order of magnitude as the change in static strength and stiffness of the spoilers, neither is large enough to be significant by itself. The overall effects of the first year of the outdoor exposure program are summarized in table 9.

Mechanical property tests are conducted generally in keeping with appropriate ASTM standards. The short beam shear specimens are tested at a nominal 4 : 1 span-to-depth ratio; the flexure specimens are tested at a nominal 32 : 1 span-to-depth ratio; and the compression specimens are gripped on fiberglass end tabs and tested in an ITTRI-designed compression fixture (ref. 2). No test results are available from the Sao Paulo, Brazil, installation as that installation has not yet been deployed for 1 year. No attempts have been made to rank the exposure sites for severity based on the first year data.

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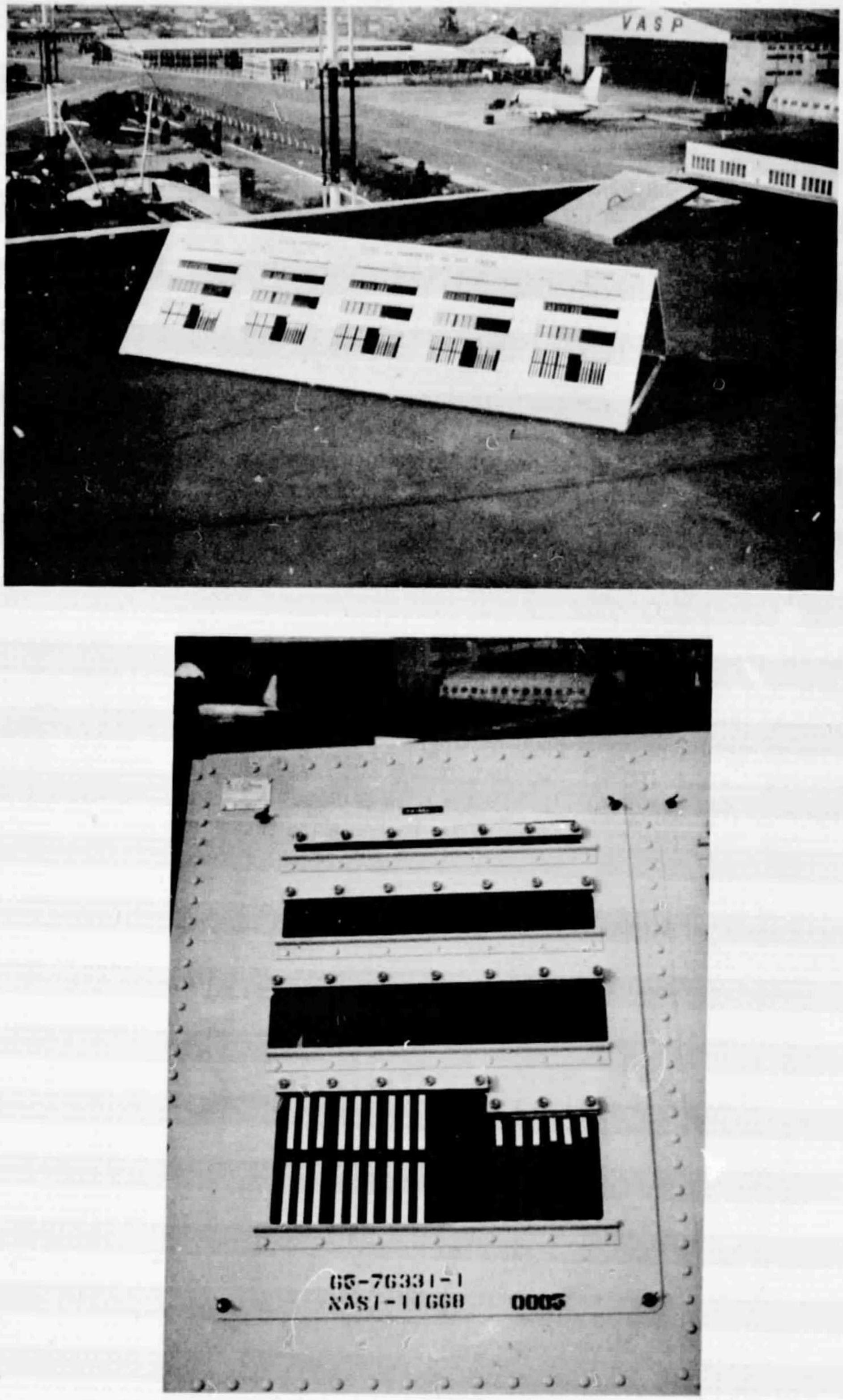


Figure 18.–Exposure Rack Installation–Sao Paulo, Brazil

Table 6.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Short-Beam Interlaminar Shear Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Av failure stress		Av wt change	
				MPa	ksi	grams	%
0 (baseline)	LaRC	T300/5209	5	77	11.2	–	–
1	LaRC	T300/5209	2	78	11.3	+0.0042	+0.58
1	Hawaii	T300/5209	3	78	11.3	+0.0034	+0.46
1	New Zealand	T300/5209	3	81	11.7	+0.0039	+0.50
1	Germany	T300/5209	3	72	10.4	+0.0032	+0.44
1	California	T300/5209	3	78	11.3	+0.0042	+0.53
1	LaRC[a] (painted specimens)	T300/5209	3	81	11.7	+0.0029	+0.34
0 (baseline)	LaRC	T300/2544	4	81	11.7	–	–
1	LaRC	T300/2544	3	74	10.7	+0.0082	+1.28
1	Hawaii	T300/2544	3	65	9.4	+0.0067	+1.07
1	New Zealand	T300/2544	3	73	10.6	+0.0075	+1.15
1	Germany	T300/2544	3	73	10.6	+0.0066	+1.09
1	California	T300/2544	3	74	10.8	+0.0071	+1.14
1	LaRC[a] (painted specimens)	T300/2544	3	80	11.6	+0.0063	+0.84
0 (baseline)	LaRC	AS/3501	5	87	12.6	–	–
1	LaRC	AS/3501	3	86	12.5	+0.0050	+0.80
1	Hawaii	AS/3501	3	89	12.9	+0.0045	+0.72
1	New Zealand	AS/3501	3	85	12.4	+0.0051	+0.84
1	Germany	AS/3501	3	78	11.3	+0.0057	+0.92
1	California	AS/3501	3	84	12.2	+0.0058	+0.89
1	LaRC[a] (painted specimens)	AS/3501	3	92	13.4	+0.0034	+0.48

[a]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

Table 7.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Flexure[a] Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Av failure stress		Av flex. modulus		Av wt change	
				MPa	ksi	GPa	psi (x 10^6)	grams	%
0 (baseline)	LaRC	T300/5209	5	1529	221.8	103.8	15.05	–	–
1	LaRC	T300/5209	3	1429	207.3	99.0	14.36	+0.0070	+0.32
1	Hawaii	T300/5209	3	1478	214.4	108.1	15.68	+0.0052	+0.23
1	New Zealand	T300/5209	3	1548	224.5	107.4	15.58	+0.0056	+0.27
1	Germany	T300/5209	3	1476	214.0	98.9	14.34	+0.0069	+0.32
1	California	T300/5209	3	1478	214.4	107.7	15.62	+0.0091	+0.41
1	LaRC[b] (painted specimens)	T300/5209	3	1470	213.2	106.8	15.49	+0.0074	+0.30
0 (baseline)	LaRC	T300/2544	5	1600	232.0	106.2	15.41	–	–
1	LaRC	T300/2544	3	1444	209.4	104.7	15.18	+0.0092	+0.50
1	Hawaii	T300/2544	3	1469	213.0	107.3	15.56	-0.0031	-0.18
1	New Zealand	T300/2544	3	1580	229.1	109.4	15.86	+0.0063	+0.34
1	Germany	T300/2544	3	1597	231.6	107.6	15.60	+0.0120	+0.62
1	California	T300/2544	3	1537	222.9	107.5	15.59	+0.0152	+0.81
1	LaRC[b] (painted specimens)	T300/2544	3	1603	232.5	111.8	16.21	+0.0138	+0.66
0 (baseline)	LaRC	AS/3501	5	1449	210.1	94.7	13.73	–	–
1	LaRC	AS/3501	3	1447	209.8	98.3	14.25	+0.0080	+0.43
1	Hawaii	AS/3501	3	1398	202.7	96.7	14.03	+0.0052	+0.28
1	New Zealand	AS/3501	3	1520	220.4	100.5	14.57	+0.0070	+0.41
1	Germany	AS/3501	3	1528	221.6	96.1	13.94	+0.0102	+0.53
1	California	AS/3501	2	1518	220.2	100.1	14.52	+0.0142	+0.74
1	LaRC[b] (painted specimens)	AS/3501	3	1638	237.6	99.8	14.48	+0.0087	+0.37

[a]Flexure specimens were fabricated from laminates with ply orientations identical to spoiler skin orientation. Specimen length is oriented in the 90° direction of the laminate.

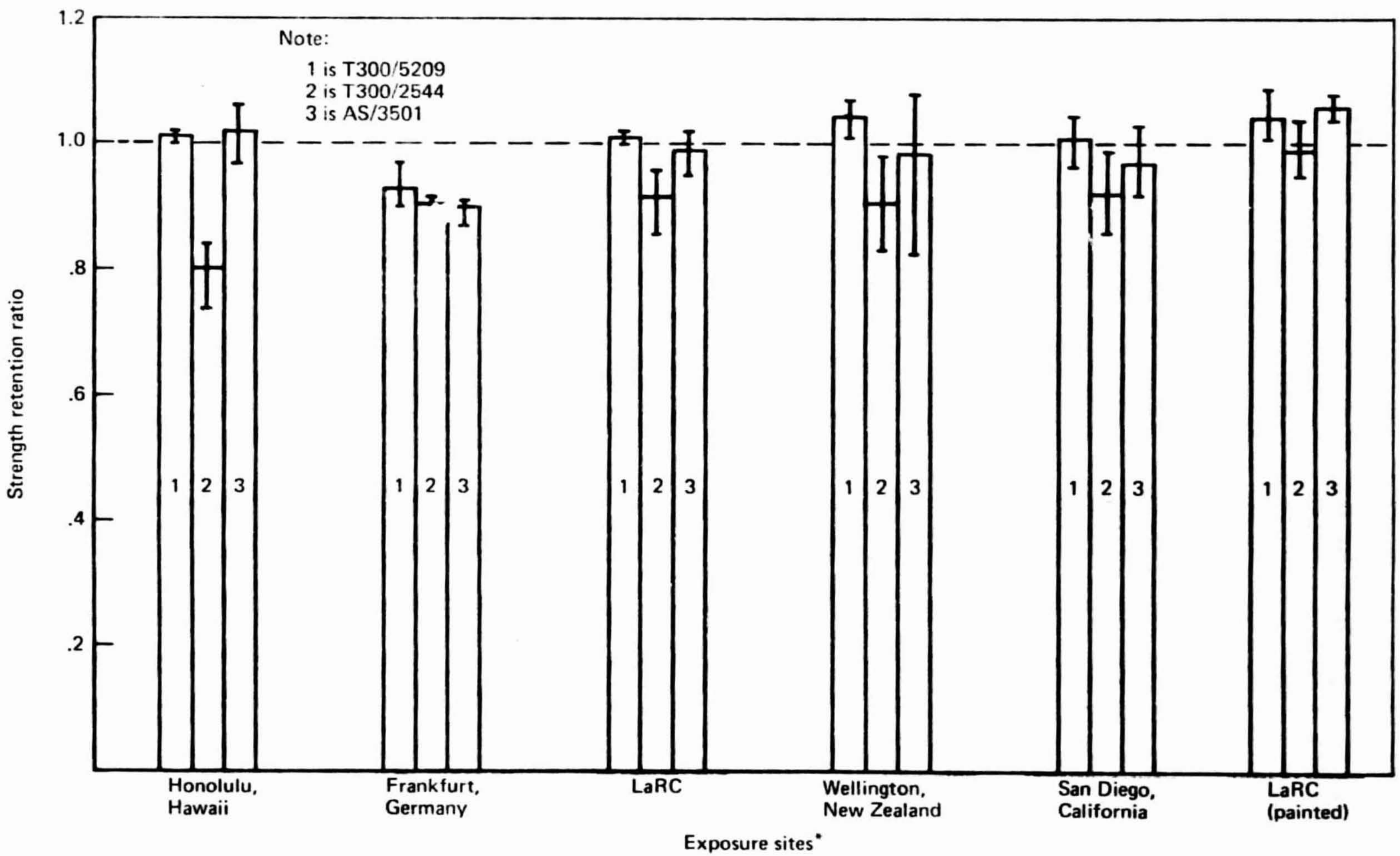
[b]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

Table 8.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Compression[a] Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Av failure stress		Av wt change	
				MPa	ksi	grams	%
0 (baseline)	LaRC	T300/5209	3	712	103.2	—	—
1	LaRC	T300/5209	3	760	110.3	+0.0494	+0.61
1	Hawaii	T300/5209	3	676	98.1	+0.0556	+0.70
1	New Zealand	T300/5209	3	647	93.8	+0.0551	+0.71
1	Germany	T300/5209	3	709	102.8	+0.0389	+0.49
1	California	T300/5209	3	716	103.9	+0.0588	+0.74
1	LaRC[b] (painted specimens)	T300/5209	3	654	94.9	+0.0361	+0.45
0 (baseline)	LaRC	T300/2544	4	1029	149.2	—	—
1	LaRC	T300/2544	3	985	142.9	+0.0544	+0.77
1	Hawaii	T300/2544	3	988	143.3	+0.0636	+0.86
1	New Zealand	T300/2544	3	865	125.5	+0.0723	+1.02
1	Germany	T300/2544	3	1022	148.3	+0.0497	+0.70
1	California	T300/2544	2	1031	149.6	+0.0560	+0.78
1	LaRC[b] (painted specimens)	T300/2544	3	1018	147.7	+0.0521	+0.74
0 (baseline)	LaRC	AS/3501	5	1107	160.6	—	—
1	LaRC	AS/3501	3	1045	151.6	+0.0440	+0.68
1	Hawaii	AS/3501	3	1080	156.6	+0.0461	+0.69
1	New Zealand	AS/3501	3	1002	145.4	+0.0493	+0.74
1	Germany	AS/3501	3	1161	168.4	+0.0374	+0.57
1	California	AS/3501	3	1105	160.2	+0.0531	+0.81
1	LaRC[b] (painted specimens)	AS/3501	3	1144	165.9	+0.0384	+0.58

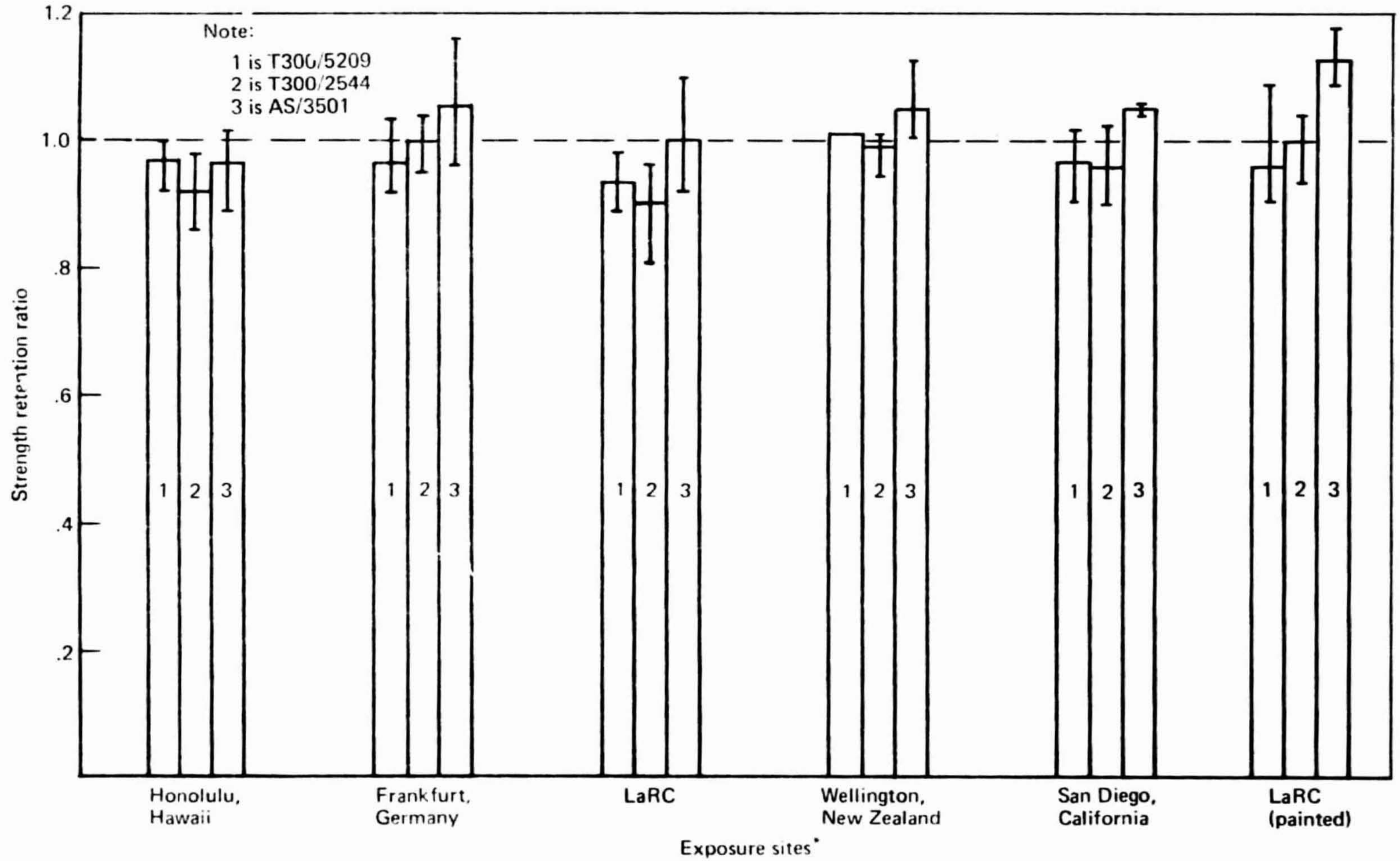
[a] Compression specimens were fabricated from laminates with ply orientations identical to spoiler skin ply orientation. Specimen length is oriented in the 90° direction of the skin laminate.

[b] Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.



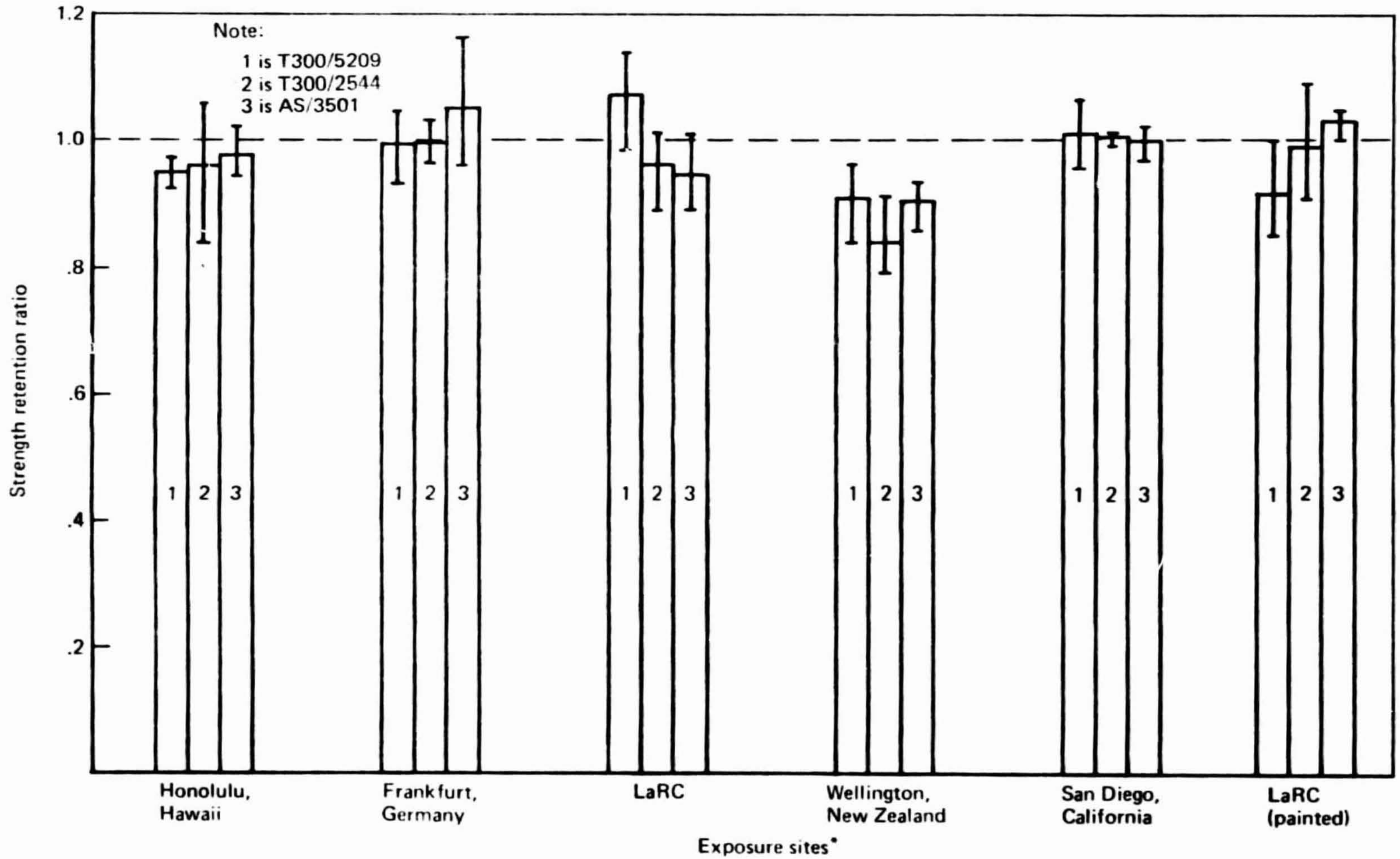
*The Sao Paulo, Brazil, site has not yet completed 1-yr exposure.

Figure 19.—Interlaminar Shear Strengths of Graphite-Epoxy Composites After 1-Year Outdoor Ground Exposure



*The Sao Paulo, Brazil, site has not yet completed 1-yr exposure.

Figure 20.—Flexure Strengths of Graphite-Epoxy Composites After 1-Year Outdoor Ground Exposure



*The Sao Paulo, Brazil, site has not yet completed 1-yr exposure.

Figure 21.—Compression Strengths of Graphite-Epoxy Composites After 1-Year Outdoor Ground Exposure

Table 9.—Overall Effects of 1-Year Outdoor Exposure (Graphite-Epoxy)

	Overall averag hange in properties				
	T300/5209	T300/2544	AS/3501	Extremes of change	Overall effect
Flex modulus	0.4% incr	1.0% incr	3.9% incr	4.7% decr (T300/5209), Germany to 6.1% incr (AS/3501), New Zealand	1.8% incr
Flexure strength	3.1% decr	4.7% decr	2.3% incr	6.5% decr, LaRC 1.2% incr, New Zealand 9.7% decr, LaRC 0.2% decr, Germany 3.5% decr, Hawaii 5.5% incr, Germany	1.8% decr
Shear strength	0%	11.1% decr	2.7% decr	7.1% decr, Germany 4.5% incr, New Zealand 19.7% decr, Hawaii 7.7% decr, California 10.3% decr, Germany 2.4% incr, Hawaii	4.6% decr
Compression strength	1.4% decr	4.9% decr	2.6% decr	9.1% decr, New Zealand 6.9% incr, LaRC 15.9% decr, New Zealand 0.3% incr, California 9.5% decr, New Zealand 4.9% incr, Germany	3.0% decr
Weight gain	0.486% gain	0.801% gain	0.670% gain		0.652% gain

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